Ring-shear test data of feldspar sand from the CNR-IGG Tectonic Modelling Laboratory at the University of Florence (Italy) (http://doi.org/10.5880/fidgeo.2020.019)

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1. Licence

2. Citation

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3. Data Description

This dataset provides internal data from ring-shear tests (RST) on a feldspar sand material that has been used in tectonic experiments by among others Montanari et al. (2017) and Zwaan et al. (2020) in the Tectonic Modelling Laboratory of CNR-IGG at the Earth Sciences Department of the University of Florence (Italy) as an analogue for brittle layers in the crust. The material has been characterized by means of internal friction coefficients μ and cohesions C as a remote service by the Helmholtz Laboratory for Tectonic Modelling (HelTec) at the GFZ German Research Centre for Geosciences in Potsdam for the Tectonic Modelling Laboratory of CNR-IGG at the Earth Sciences Department of the University of Florence (CNR-UF)

According to our analysis the material behaves as a Mohr-Coulomb material characterized by a linear failure envelope. Internal peak, dynamic and reactivation friction coefficients are μP= 0.72, μD= 0.67, and μR= 0.72 respectively. Internal cohesions C are in the range of 60 to 120 Pa. Note however that these values differ from those reported by Montanari et al. (2017), who used empirical methods to determine material properties and find a friction angle of ca. 57˚ (i.e. a friction coefficient of ca. 1.5).

3.1. Materials tested

The material tested is a fine feldspar sand sold under the product ID: FS900SF by the company Kaolinwerke-AKW (Montanari et al. 2017). The grains are angular and the grain size distribution is in the range of 20-100 µm with a significant fine fraction (50% <30 µm). The bulk density of the material is ρ = ~1000 kg m-3 when poured from ca. 10 cm height. Additional information concerning the sand can be found in Montanari et al. (2017).

3.2. Measurement procedure

The data presented here are derived by ring shear testing using a SCHULZE RST-01.pc (Schulze, 1994, 2003, 2008) at the Helmholtz Laboratory for Tectonic Modelling (HelTec) of the GFZ German Research Centre for Geosciences in Potsdam. The RST is specially designed to measure friction coefficients μ and cohesions C in loose granular material accurately at low confining pressures and shear velocities similar to sandbox experiments. In this tester, a sand layer is sheared internally at constant normal stress σ_N and shear velocity v while shear force and lid displacement (corresponds to volume change ΔV) are measured continuously. For more details see Klinkmüller et al. (2016) and Ritter et al. (2016).

3.2.1. Sample preparation and test conditions

Each sample has been carefully prepared by the same person and measured consistently following the same protocol. The measurements presented here correspond to internal friction, i.e. shearing inside the material. Preparation included pouring from 10 cm height into a shear cell of type No. 1. Normal force, shear force, velocity and lid displacement (volume change) were measured at 100 Hz and then down sampled to 5 Hz. Laboratory conditions were air conditioned during all the measurements (Temperature: 23°C, Humidity: 45%).

3.2.2. RST (Ring-shear test) procedure

In a RST a shear velocity of v = 30 mm min^{-1} is imposed. 18 measurements are done at normal stresses of σ_N = 500, 1000, 2000, 4000, 8000, and 16000 Pa (3 repetitions per stress level). During the measurement the material is sheared for initially 3 minutes. During this period the shear stress τreaches a peak (= peak friction) and then drops to a plateau indicating shear has localized into a shear zone (= dynamic friction). The sample is then unloaded by shortly reversing rotation and immediately re-sheared for 3 minutes during which shear stress τ reaches a second peak (= reactivation friction) simulating reactivation of an existing shear zone.

Table 1: Sample overview *(CNR-UF = CNR-IGG lab at the University of Florence, GFZ = German Research Centre for Geosciences in Potsdam).*

ID (GFZ)	ID (CNR-UF)	Material	Bulk density [kg m^{-3}]	File name
468-01	FS900SF	Feldspar sand	1000	468-01_Feldsparsand_Florence_..., 468-01_Feldsparsand_Florence_ts_...

3.3. Analysis method

3.3.1. RST analysis: Friction coefficients and cohesion

From the resulting shear stress curves (see e.g. Figure 2) three characteristic values (strengths) have been picked manually:

(1) The shear strength τ*at ***peak friction*** corresponding to the first peak in the shear curve reflecting hardening-weakening during strain localization
(2) the shear strength τ*at ***dynamic friction*** corresponding to the plateau after localization and representing friction during sliding
(3) the shear strength τ*at ***reactivation friction*** corresponding to the second peak and representing static friction during reactivation of the shear zone.

We performed regression analysis of these friction data by means of linear regression in two ways:

(1) A linear regression through all data pairs of shear strength τ*and normal stress σ_N. The slope of the linear regression corresponds to the friction coefficient μ and the y-axis intercept to cohesion

C(see e.g. Figure 3). This method assumes that the material behaves strictly as a Mohr-Coulomb material, i.e. has a linear failure envelope.

(2) Calculating all possible two point slopes (friction coefficientμ) and y-axis intercepts (cohesion C) for mutually combined data pairs of shear strength τ*and normal stress σ_N. These data (i.e. all individual $\mu$and C) are then evaluated by means of univariate statistics by calculating mean and standard deviation and comparing the probability density function (pdf) to that of a normal distribution (see e.g. Figure 4). This method overcomes the limitation of the analysis to Mohr-Coulomb material and allows for non-linear failure envelopes (Santimano et al., 2015).

In case values for μ and C as derived from the two methods are identical (within standard deviation), the material is properly characterized by a straight Mohr-Coulomb failure envelope.

3.3.2. Python-based analysis and visualization

The data has been analyzed using the Python based software 'RST-Evaluation' (Rudolf, M., & M. Warsitzka, 2019) which is explained in Warsitzka et al. (2019). The software uses the raw data recorded by a National Instruments compactRIO that is stored within *.tdms files. It produces the various plots in *.pdf format and several results as txt files. For details see chapter 4.

4. File description

The following files are provided in the folder "Data files" with 'XXX' being the internal naming scheme of the project (468-01_Feldsparsand_Florence):

(i) RST shear curve time series data ("XXX_ts.txt"; Table 2)
(ii) RST shear curve time series plot ("XXX_ts.pdf"; Figure 1)
(iii) RST picked friction data ("XXX_peak.txt", "XXX_dynamic.txt", "XXX_reactivation.txt"; example Table 3)
(iv) RST friction plot ("XXX_linregr.pdf"; example Figure 2)
(v) RST histograms of friction data ("XXX_hist.pdf"; example Figure 3)
(vi) RST result files ("XXX_fricmut.txt", "XXX_fricstd.txt", "XXX_lidpos.txt")
(vii) Tdms files raw data files ("XXX [f=5.00Hz][<date_time>]")

An overview of all files of the data set is given in the **List of Files.**

4.1. Shear curvedata

Shear curve data are given as (i) time series (ts) data in .txt-format ("File name_ts.txt") and visualized as (ii) shear stress τ versus shear displacement d plots ("Filename_ts.pdf") (Figure 1).

Table 2: Example of shear curve time series data (468-01).*First line is header. First column is time (in s). Columns 2-19 are shear forces (in N) for corresponding normal stresses as specified in the header of the respective columns (6 stress levels from 500 to 16.000 Pa, three repetitions each stress level).*

Time [s]	Normal stress [Pa]: 1130	4104	16042	…
0.0	13.9685153961181	-3.04927611351013	63.3901672363281	…
0.2	…	…	…	…
…	…	…	…	…

Furthermore, the raw data can be found in the binary *.tdms files provided in the "raw Data XXX" folder. They can be read using several means that are openly available, e.g. a C-Library (TDM-C-DLL), a Python package (npTDMS), OpenOffice Calc extension, or a Microsoft Excel extension (see www.ni.com for details).

4.2. RST Friction data

Friction data are given as (iii) data pairs (normal stress σ_N and shear strength τ^*; Table 3) for peak, dynamic and reactivation friction in txt format ("File name_peak.txt", "File name_dynamic.txt", "File name_reactivation.txt"). They are visualized by (iv) plotting into Mohr Space (normal stress σ_N vs. shear stress τ) including a linear regression (File name_linregr.pdf"; Figure 2). The results of the regression analysis (see 3.3) are plotted in (v) histograms for friction coefficients μ and cohesions C ("File name_hist.pdf"; Figure 3).

Table 3: Example of friction data (468, peak). *First line is header. First column is normal stress σ_N (in Pa). Second column is shear strength τ^*(in Pa).*

Normal stress [Pa]	Shear strength [Pa]
1000.0	808.26
4000.0	2986.76
…	…

5. Results

Our analysis reveals that the tested material behaves as a Mohr-Coulomb material characterized by a linear failure envelope. Values of friction coefficients μ and cohesions C are listed in Table 4. Internal peak, dynamic and reactivation friction coefficients are μP= 0.72, μD= 0.67, and μR= 0.72, respectively. Internal cohesions C are in the range of 70 to 120 Pa. Note however that these values differ from those reported by Montanari et al. (2017), who used empirical methods to determine material properties and find a friction angle of ca. 57° (i.e. a friction coefficient of ca. 1.5). The results presented in Table 4 are stored in the RST result files ("XXX_fricmut.txt", "XXX_fricstd.txt").

Table 4: Summary of RST data *(CNR-UF = CNR-IGG lab at the University of Florence, v = shear velocity)*

Parameter	Symbol	Unit	Linear least-squares regression method		Mutual two-point regression method	
			Value	Standard deviation	Value	Standard deviation
468-01_CNR-UF_Feldsparsand_Florence						
Coefficient of peak friction	μ_P	-	0.719	0.002	0.731	0.023
Peak cohesion	C_P	Pa	120.82	12.96	108.52	57.33
Coefficient of dynamic friction	μ_D	-	0.673	0.002	0.682	0.016
Dynamic cohesion	C_D	Pa	72.28	17.92	59.31	80.17
Coefficient of reactivation friction	μ_R	-	0.723	0.002	0.734	0.018
Reactivation cohesion	C_R	Pa	83.38	14.6	71.05	60.98

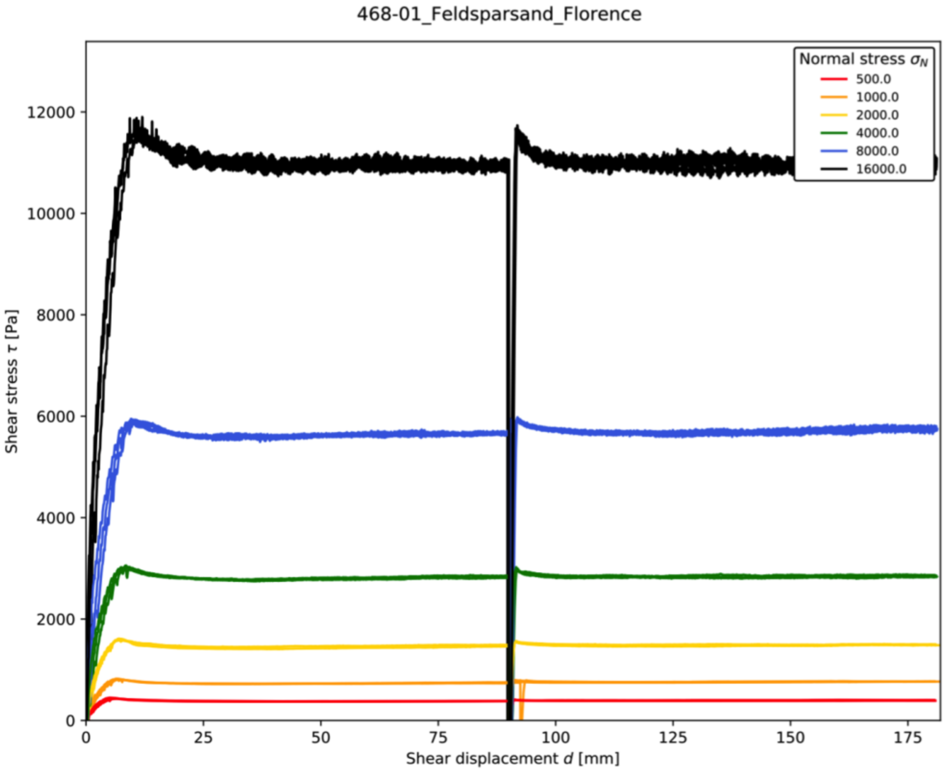

Figure 1: Example of shear curve plot (468-01).*Y-axis is shear stress τ, x-axis is shear displacement d. Each data set consists of 18 shear curves corresponding to 6 levels of normal stress σ_N with 3 repetitions each stress level.*

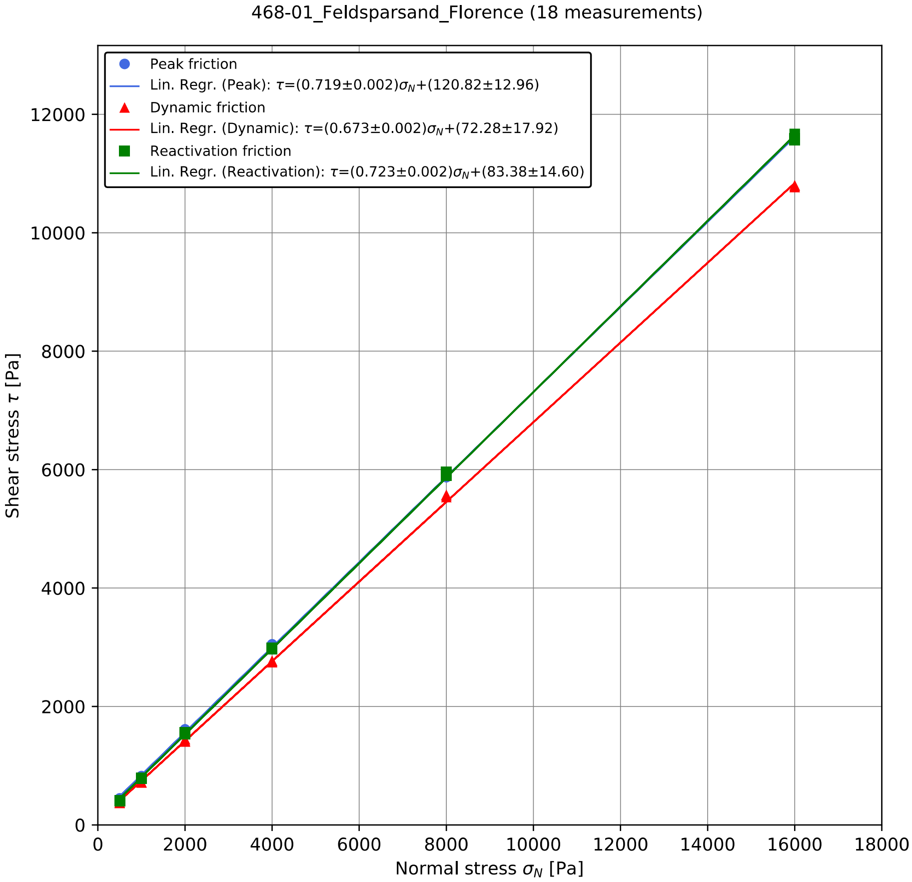

Figure 2: Example of friction plot (468-01). *Plot of all data pairs in the Mohr space (normal stress σN vs. shear stress τ) including curves of the corresponding linear least-squares regression.*

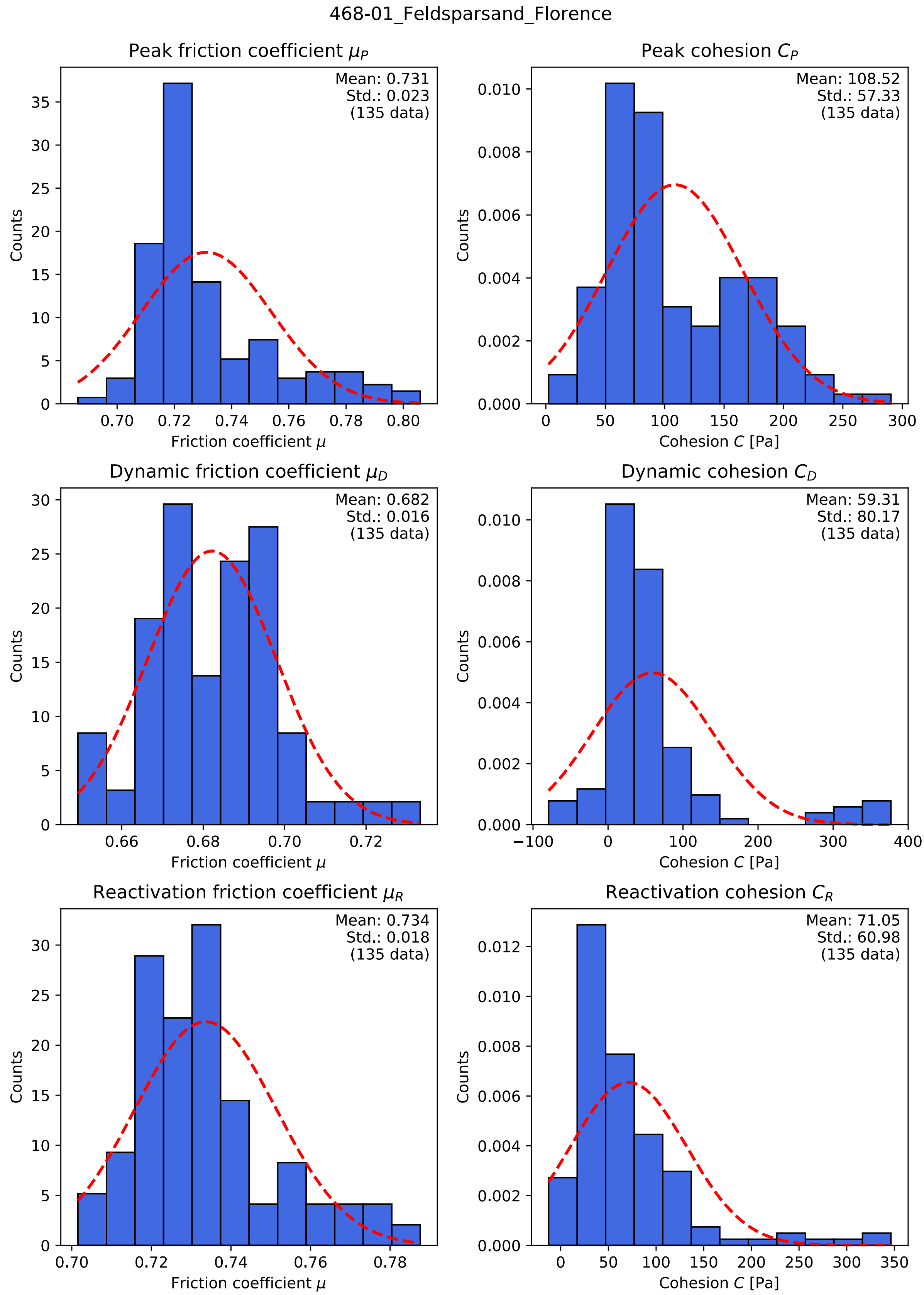

Figure 3: Example of histogram plot (468-01). *Histograms of mutual two-point regression results for slope (friction coefficient μ) and y-axis intercept (cohesion C). Red curves are synthetic normal distributions with the same mean and standard deviation (std.) as the data set for comparison.*

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